ADVANTAGES OF USING GEOCENTRIC LATITUDE IN CALCULATING DISTANCES.

By
B. Gutenberg[1]) and **C. F. Richter**[2]), Pasadena, Calif.

(With 1 figure.)

Zusammenfassung: Bei der Berechnung von Entfernungen auf der Erdoberfläche wurde seither die geographische (= geodätische oder nahezu gleich der astronomischen) Breite benutzt. Dieser entspricht jedoch nicht der in der Seismologie benötigte Zentriwinkel α (Fig. 1), sondern ein größerer Winkel β, der gemäß Gleichung (2) mit α verknüpft und im Maximum über 11′ größer als α ist. Wenn ein Epizentrum in mittleren südlichen Breiten, die Station — wie in den meisten Fällen — in mittleren nördlichen Breiten liegt, kann somit der Zentriwinkel Δ zwischen beiden bis zu 23′ falsch werden, wenn man die geographische Breite der Berechnung zugrunde legt. Bei Verwendung der geozentrischen Breite α tritt kein solcher Fehler auf. Für exakte Rechnungen kann man außerdem die Höhe H der Station bzw. des Herdes über oder unter einer Bezugskugel verwenden. Als solche wird die Kugel mit dem Umfang 40000 km (Radius 6366 km) benutzt. Die sich dann ergebenden Werte von H sind in Tab. 1 zu finden, ebenso der Effekt Δt von H auf die Laufzeit der direkten Longitudinalwellen. Berechnet man Entfernungen längs der Oberfläche der erwähnten Kugel, so erhält man Fehler sowohl bei Verwendung der geographischen wie bei Verwendung der geozentrischen Breite (falls H nicht berücksichtigt wird), doch sind sie im zweiten Falle (E_α in Tab. 2) kleiner. (Der maximale Wert von E_β ist $\pm$ 32 km für $\Delta = 90°$.) Tab. 2a gibt die entsprechenden Differenzen für 10°, gemessen in km auf der Bezugskugel auf einem Meridian zwischen den angegebenen Breiten φ minus dem entsprechenden Werte auf dem Ellipsoid von CLARKE, Tab. 2b die entsprechenden Unterschiede für 10° auf den Breitekreisen. Zum Schlusse wird empfohlen, allen seismischen Untersuchungen den unter Benutzung der geozentrischen Breite berechneten Zentriwinkel Δ zugrunde zu legen. Die geozentrische Breite sowie die Höhe H über der Bezugskugel ist für eine Reihe von Stationen in Tab. 3 zusammengestellt, zusammen mit der Länge λ. Die Umrechnung der Entfernungen in km erfolgt am besten unter Zugrundelegung der Kugel mit dem Umfang 40000 km.

In seismological calculation of distance it has hitherto been customary to treat the earth as spherical. The error thus introduced has generally been held to be small, as the difference between the equatorial

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[1]) Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena.

[2]) Carnegie Institution of Washington, Seismologic Research, Pasadena.

and polar radii is 22 km.; this would affect the travel time of longitudinal waves by a quantity of the order of 2 seconds.

The recent noteworthy improvement in timekeeping at many stations calls for a re-examination of such small sources of error. On re-examination it appears that there exists a further error, originating in the application of spherical coördinates to the ellipsoid. The angular distance, Δ, is usually calculated by the formula

(1) $$\cos \Delta = \cos \varphi_1 \cos \varphi_2 \cos (\lambda_2 - \lambda_1) + \sin \varphi_1 \sin \varphi_2$$

in which φ_1, φ_2 are the latitudes of the two points, and λ_1, λ_2 are the corresponding longitudes.

The positions of points on the earth's surface, including seismological stations, are usually given in terms of the longitude and the geographic or geodetic latitude (or the astronomical latitude, which differs only very slightly). But a serious question is raised if we attempt to compute Δ by substituting the geographic latitudes for φ_1, φ_2 in the above formula.

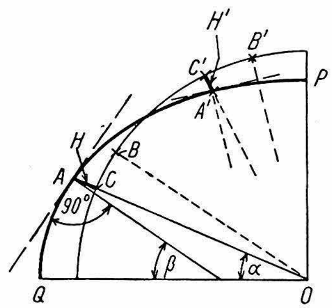

Fig. 1. A = point on the spheroid, α = geocentric latitude, β = geographic latitude, C = corresponding point on the sphere, if the geocentric latitude is used, but the height H of A over the sphere is neglected, B = corresponding point on the sphere, if the geographic is used. B', C', H' have similar meaning the point A' being closer to the pole P.

Figure 1 represents a quadrant of a section of the earth and of a concentric sphere, the ellipticity being greatly exaggerated. P is the pole, O the center and Q a point on the equator. The geographic latitude of a point A on the earth's surface is given by the angle β between the normal at A and the equatorial plane. The geocentric latitude of the same point A is the angle α between the radius OA and the equatorial plane.

The use of geographic latitudes in (1) is equivalent to replacing A by the point B on the sphere, such that OB is parallel to the normal at A; the use of geocentric latitudes is equivalent to replacing A by C, which lies on the same radius OCA. The question is now which of these two procedures is more appropriate to the purposes of seismology. One advantage of using geocentric latitudes is that in this case the calculated angle Δ is the actual angle subtended by the two given points at the center of the earth; while the use of geographic latitudes gives an entirely distinct angle, of less simple geometric significance. The exact relation of the two latitudes α and β is given by

$$(2) \qquad \tan \alpha = (1-e^2) \tan \beta$$

where e is the eccentricity of the ellipse in figure 1. Since e for the earth is small, an approximation suffices for our purposes, and we may take

$$(3) \qquad \beta - \alpha = 11.67' \sin 2 \beta .$$

The exact quantity 11.67′ is based on the eccentricity of the CLARKE[1]) spheroid, but will not materially differ if other usual spheroids are assumed.

From (3) it is clear that the difference between the two latitudes reaches a maximum value of over 11′ when the geographic latitude is 45° (north or south). In the two extreme cases (*a*) of a source near latitude 45°, and a station near latitude 45° in the opposite hemisphere but on the same meridian, and (*b*) both source and station near 45° latitude in the same hemisphere, but on opposite meridians, the distance Δ computed using geographic latitudes will be respectively greater or less than that computed using geocentric latitudes, by more than 23′. As Δ is near 90° this corresponds to a difference of $\pm$ 2 seconds in the travel time of longitudinal waves. The error is over 10′ at latitudes between 30° and 60°, which includes most stations of the world.

In the preparation and use of seismological travel time tables it is assumed that the earth is spherical; and these travel times are ordinarily given in terms of an angle Δ. It is taken for granted that for equal Δ the travel times are equal. This assumption is partially justified if Δ is the actual angle at the center, calculated from (1) by the use of geocentric latitudes; but it is a very questionable practice when, as is usual, Δ is calculated from geographic latitudes. It is true that the interior properties of the earth have not a spherical, but an ellipsoidal distribution, so that the travel time must vary with position of source and station as well as with central angle. But the use of geographic latitudes, far from taking into account this effect, further complicates and obscures it.

In working with geocentric latitudes we can calculate the elevation H (figure 1) of the stations, above or below a mean sphere, with radius intermediate between the polar and equatorial radii of the earth. Very convenient for this purpose is the sphere with circumference 40000 km., and radius 6366 km. The extreme values of H are then +12 km. at the

[1]) The spheroid of CLARKE has been used as the base of the "Smithsonian Geographical Tables".

equator and -10 km. at the poles. The values of H for every $10°$ of latitude are given in table 1. Δt is the correction to be applied to the

Table 1.

Lat.	0	10	20	30	40	50	60	70	80	90 °
H	12	12	10	7	3	— 1	— 4	— 7	— 9	— 10 km.
Δt	1.1	1.1	0.9	0.6	0.2	— 0.1	— 0.4	— 0.6	— 0.8	— 0.9 sec.

travel time according to the formula $t = t_s + \Delta t$ in which t_s is the tabulated travel time on the assumption that the station and source lie at the surface of the sphere of 40000 km. circumference. The values of Δt given in table 1 are calculated from the sufficiently approximate formula

$$\Delta t = \frac{H \cos i}{V}$$

where i is the angle of incidence and V the average velocity. For longitudinal waves $\cos i/V$ lies between 0.08 and 0.1 sec./km. (for distances over $10°$). Therefore the value of Δt for longitudinal waves, for distances over $10°$, can be assumed to be $\Delta t = H\,(\text{km.})/11$. This gives the tabulated values.

In this way we correct for the fact that the station does not lie on the assumed spherical surface. A second correction, additive to this, arises at the source of the shock; and if the depth were known or could be assumed a priori, a correction could be calculated and applied uniformly to all the tabulated travel times. But since the depth is not a given quantity, it is best to consider it as combined with the elevation H and treat the result in the ordinary manner used in considering depth of focus. It is worth noticing that in this way there may arise, near the equator, apparent cases of "high focus".

In seismological tables there is often given, in addition to or in place of the angle Δ, a distance over the surface in kilometers. If this distance is calculated from the radius of an arbitrary sphere, such as that of 40000 km. circumference, no difficulty arises, and the value in kilometers is of some practical convenience. But if an attempt is made to derive the true distance over the actual surface, it is possible to ask whether the use of the geographic or the geocentric latitude gives the better approximation. The situation then becomes very complex.

If we compare distances calculated from the Clarke spheroid with distances calculated from the sphere of 40000 km. circumference, we obtain the results exhibited in tables 2a and 2b. The columns headed E_α and E_β give the excess (positive or negative) of the arc on the sphere over the arc on the spheroid, between two points having the geocentric or geographic latitudes given under φ; the two points are on the same meridian at the two latitudes (in the same hemisphere) given in the φ column. In table 2b the points are on the same parallel, and therefore are both at the latitude given in the φ column, and differ by $10°$ in longitude. E_α and E_β give the excess in the length of $10°$ of the parallel on the sphere over that on the spheroid, for the two cases when φ is the geocentric (E_α) or geographic (E_β) latitude.

Table 2a.

$\varphi°$	E_α (km.)	E_β (km.)
0—10	— 2.1	+ 5.3
10—20	— 1.9	+ 4.6
20—30	— 1.4	+ 3.4
30—40	+ 1.0	+ 1.7
40—50	— 0.2	— 0.2
50—60	— 1.5	— 2.2
60—70	+ 0.9	— 3.9
70—80	+ 1.4	— 5.1
80—90	+ 1.6	— 5.8

Table 2b.

$\varphi°$	E_α (km.)	E_β (km.)
0	— 2.1	— 2.1
10	— 1.9	— 2.2
20	— 1.6	— 2.4
30	— 0.9	— 2.6
40	— 0.5	— 2.8
50	+ 0.1	— 2.8
60	+ 0.3	— 2.4
70	+ 0.4	— 1.9
80	+ 0.3	— 1.0

It is clear that the errors in these calculations are on the whole much less when geocentric latitudes α are used than when geographic latitudes β are used.

Besides these, use is occasionally made of the "reduced latitude", γ, which is defined by

$$\tan \gamma = (1 - e^2)^{-\frac{1}{2}} \tan \alpha .$$

Its numerical value is very nearly the mean of α and β. The errors introduced by using the reduced latitude are of the same order as those introduced by using the geocentric latitude; while the angle Δ calculated from (1) has much less simple geometrical meaning than that found using α.

For seismological use the quantities required for the computation of distance are seen to be the longitude, the geocentric latitude, and the height H above the arbitrary sphere (circumference 40000 km.). On the right side of table 3 these are given for a number of stations; the geographic latitude and the height h above sea level appear on the left. Except in the cases marked with an asterisk, the station constants are from information supplied by the stations themselves, either in correspondence with the Seismological Laboratory at Pasadena or in their own published bulletins. The coördinates have been checked very care-

Table 3.

Geographic Latitude β	Height above sea level h in km.	Station	Longitude (Greenwich) λ	Geocentric Latitude α	Height above (+) or under (—) sphere with $r = 6366$ km. H in km.
° ′			° ′	° ′	
68 21 N	0.4	Abisko*	18 49 E	68 13 N	— 6
34 56 S	0.0	Adelaide	138 35 E	34 45 S	+ 5
13 24 N	0.0	Agaña (Guam)	144 38 E	13 19 N	11
36 48 N	0.3	Alger-Bouzaréah	3 02 E	36 37 N	5
38 21 N	0.0	Alicante	0 29 W	38 10 N	4
22 32 N	0.0	Alipore-Calcutta	88 20 E	22 24 N	9
43 16 N	0.8	Almata	76 57 E	43 05 N	3
36 51 N	0.1	Almeria	2 28 W	36 40 N	4
3 42 S	0.0	Amboina	128 10 E	3 41 S	12
40 45 N	0.5	Andijan	72 22 E	40 34 N	3
42 17 N	0.3	Ann Arbor	83 44 W	42 05 N	3
13 48 S	0.0	Apia	171 47 W	13 43 S	11
40 23 N	0.0	Baku	49 54 E	40 11 N	3
8 58 N	0.0	Balboa Heights	79 33 W	8 54 N	12
41 25 N	0.4	Barcelona-Fabra	2 08 E	41 15 N	3
6 11 S	0.0	Batavia	106 50 E	6 09 S	12
44 49 N	0.1	Beograd	20 27 E	44 38 N	1
60 24 N	0.0	Bergen	5 18 E	60 14 N	— 4
37 52 N	0.1	Berkeley	122 16 W	37 41 N	+ 4
53 24 N	0.1	Bidston (Liverpool)* . . .	3 04 W	53 13 N	— 2
18 54 N	0.0	Bombay (Colaba)	72 49 E	18 46 N	+ 10
45 41 N	1.5	Bozeman	111 02 W	45 29 N	3
47 29 N	0.1	Budapest	19 04 E	47 18 N	0
42 56 N	0.2	Buffalo	78 51 W	42 44 N	2
8 56 N	0.0	Butuan	125 32 E	8 53 N	11
22 32 N	0.0	Calcutta	88 20 E	22 24 N	9
33 58 S	0.0*?	Cape Town	18 28 E	33 47 S	5
51 30 N	0.1	Cardiff*	3 10 W	51 19 N	— 1
39 08 N	0.0	Carloforte*	8 19 E	38 57 N	3
37 12 N	0.8	Cartuja (Granada)	3 36 W	37 01 N	5
37 30 N	0.0	Catania*	15 05 E	37 19 N	4
38 02 N	0.2	Charlottesville	78 31 W	37 51 N	4
50 05 N	0.4	Cheb (Eger)	12 23 E	49 53 N	— 0
41 47 N	0.2	Chicago (U. S. C. G. S.) . .	87 37 W	41 35 N	3
40 04 N	0.1	Chiufeng	116 06 E	39 52 N	1
46 51 N	0.6*	Chur	9 32 E	46 39 N	1
18 54 N	0.0	Colaba-Bombay	72 49 E	18 46 N	10
6 54 N	0.0	Colombo*	79 52 E	6 52 N	12
34 00 N	0.1	Columbia	81 02 W	33 49 N	5
52 06 N	0.0*	De Bilt	5 11 E	51 55 N	— 1

Table 3 (Continuation).

Geographic Latitude β	Height above sea level h in km.	Station	Longitude (Greenwich) λ	Geocentric Latitude α	Height above (+) or under (—) sphere with $r = 6366$ km. H in km.
° ′			° ′	° ′	
33 13 N	0.2*	Denton	97 08 W	33 02 N	+ 6
39 41 N	1.7	Denver	104 57 W	39 29 N	5
55 56 N	0.1	Edinburgh*	3 11 W	55 45 N	— 3
50 05 N	0.4	Eger (Cheb)	12 23 E	49 53 N	— 0
0 04 N	1.1	Entebbe*	32 28 E	0 04 N	+ 13
50 13 N	0.8	Feldberg (Taunus)	8 27 E	50 02 N	0
43 47 N	0.1	Firenze-Ximeniano	11 15 E	43 35 N	2
38 48 N	0.2	Florissant	90 22 W	38 37 N	4
40 52 N	0.0	Fordham (New York)	73 53 W	40 40 N	3
38 54 N	0.0	Georgetown (Washington)	77 04 W	38 43 N	4
51 33 N	0.3	Göttingen	9 58 E	51 22 N	— 1
47 05 N*	0.4	Graz	15 27 E	46 53 N	1
13 24 N	0.0	Guam (Agaña)	144 38 E	13 19 N	11
36 08 N	1.1	Haiwee	117 58 W	35 57 N	6
44 38 N	0.0*	Halifax	63 36 W	44 26 N	1
53 34 N	0.0	Hamburg	9 59 E	53 22 N	— 2
42 30 N	0.1*?	Harvard University	71 34 W	42 19 N	+ 2
19 26 N	1.2	Hawaii (Volc. Obs.)	155 16 W	19 19 N	11
49 24 N	0.6	Heidelberg (Königstuhl)*	8 43 E	49 12 N	0
60 10 N	0.0	Helsingfors*	24 58 E	60 00 N	— 4
29 51 N	0.1	Helwan	31 20 E	29 41 N	+ 7
48 43 N	0.4	Hohenheim	9 13 E	48 31 N	0
22 18 N	0.0	Hong Kong	114 10 E	22 10 N	9
21 18 N	0.0	Honolulu (University)	157 49 W	21 10 N	9
12 03 S	3.4	Huancayo	75 20 W	11 58 S	15
33 35 N	0.0	Hukuoka	130 25 E	33 24 N	5
47 16 N	0.6	Innsbruck	11 24 E	47 04 N	1
52 16 N	0.5	Irkutsk	104 19 E	52 05 N	— 1
34 58 N	0.0	Itô	139 06 E	34 47 N	+ 5
61 12 N	0.0*?	Ivigtut	48 11 W	61 02 N	— 4
50 56 N	0.2	Jena	11 35 E	50 45 N	— 1
26 11 S	1.8	Johannesburg*	28 04 E	26 02 S	+ 10
49 01 N	0.1	Karlsruhe	8 25 E	48 49 N	— 0
51 28 N	0.0	Kew	0 19 W	51 17 N	— 1
34 41 N	0.1	Kôbe*	135 11 E	34 30 N	+ 5
55 41 N	0.0	København	12 27 E	55 30 N	— 3
10 14 N	2.3	Kodaikanal	77 28 E	10 10 N	+ 14
54 50 N	0.0	Königsberg	20 30 E	54 39 N	— 2
33 33 N	0.0	Kôti	133 32 E	33 23 N	6
33 49 N	0.9	Ksara	35 53 E	33 39 N	6

Table 3 (Continuation).

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° ′			° ′	° ′	
55 45 N	0.2	Kucino	37 58 E	55 34 N	— 2
46 03 N	0.3	Laibach (Ljubljana) . . .	14 31 E	45 51 N	+ 1
32 52 N	0.0	La Jolla	117 15 W	32 41 N	6
16 30 S	3.7	La Paz	68 08 W	16 23 S	14
34 55 S	0.1	La Plata	57 56 W	34 44 S	5
51 20 N	0.1	Leipzig	12 24 E	51 09 N	— 1
49 50 N	0.3	Lemberg (Lwów)	24 01 E	49 39 N	— 0
37 20 N	1.3	Lick Observatory	121 39 W	37 09 N	+ 5
34 47 N	0.1*	Little Rock	92 21 W	34 36 N	5
55 42 N	0.0	Lund*	13 11 E	55 31 N	— 2
49 50 N	0.3	Lwów (Lemberg)	24 01 E	49 39 N	— 0
7 13 S	1.6	Malabar	107 37 E	7 10 S	+ 13
36 44 N	0.1	Málaga	4 25 W	36 32 N	4
14 35 N	0.0	Manila	120 59 E	14 29 N	11
43 18 N	0.1	Marseille*	5 24 E	43 07 N	2
3 35 N	0.0	Medan	98 41 E	3 34 N	12
37 50 S	0.0	Melbourne*	144 58 E	37 39 S	4
43 02 N	0.2	Milwaukee*	87 55 W	42 50 N	2
39 08 N	0.1	Mizusawa	141 08 E	38 57 N	3
45 00 N	0.2	Moncalieri*	7 42 E	44 48 N	2
34 14 N	1.7	Mt. Wilson	118 03 W	34 03 N	7
48 09 N	0.5	München	11 37 E	47 57 N	1
32 44 N	0.1	Nagasaki	129 53 E	32 33 N	6
35 10 N	0.1	Nagoya.	136 58 E	34 59 N	5
32 03 N	0.1	Nanking	118 47 E	31 53 N	6
28 23 N	0.0	Nase	129 30 E	28 13 N	7
47 00 N	0.5*	Neuchâtel.	6 57 E	46 48 N	1
35 06 N	0.0	Numadu	138 51 E	34 55 N	5
34 39 N	0.0	Osaka	135 32 E	34 28 N	5
45 24 N	0.1	Ottawa.	75 43 W	45 12 N	1
51 46 N	0.1	Oxford	1 15 W	51 34 N	— 1
48 49 N	0.1	Paris (Parc St. Maur)* . .	2 30 E	48 37 N	0
34 09 N	0.3	Pasadena	118 10 W	33 58 N	6
31 57 S	0.1	Perth, W. A.*.	115 50 E	31 47 S	6
20 48 N	0.0?	Phu-Lien*	106 38 E	20 41 N	10
40 27 N	0.3	Pittsburgh	79 57 W	40 16 N	3
18 33 N	0.0*	Port au Prince	72 20 W	18 26 N	10
52 23 N	0.1*	Potsdam	13 04 E	52 12 N	— 1
50 04 N	0.2*	Praha	14 26 E	49 53 N	— 0
59 46 N	0.1	Pulkovo	30 19 E	59 36 N	— 4

Table 3 (Continuation).

Geographic Latitude β	Height above sea level h in km.	Station	Longitude (Greenwich) β	Geocentric Latitude α	Height above (+) or under (—) sphere with $r = 6366$ km. H in km.
° ′			° ′	° ′	
0 13 S	2.8	Quito	78 30 W	0 13 S	+ 15
47 47 N	0.4	Ravensburg	9 37 E	47 35 N	1
39 32 N	1.4	Reno*	119 48 W	39 21 N	5
64 09 N	0.0*	Reykjavik	21 57 W	64 00 N	— 5
22 54 S	0.0	Rio de Janeiro	43 13 W	22 45 S	+ 9
34 00 N	0.3	Riverside	117 22 W	33 49 N	6
33 50 S	0.0	Riverview-Sydney	151 10 E	33 39 S	5
38 38 N	0.2	St. Louis	90 14 W	38 27 N	4
39 40 N	0.7	Samarkand	66 59 E	39 29 N	4
36 28 N	0.0	San Fernando*	6 12 W	36 17 N	4
18 23 N	0.1	San Juan	66 07 W	18 16 N	10
34 27 N	0.1	Santa Barbara	119 43 W	34 16 N	5
37 21 N	0.0	Santa Clara	121 57 W	37 10 N	4
33 27 S	0.6	Santiago de Chile	70 42 W	33 16 S	6
52 08 N	0.5*	Saskatoon	106 30 W	51 57 N	— 1
70 29 N	0.1	Scoresby-Sund	21 57 W	70 22 N	— 9
47 39 N	0.0	Seattle	122 18 W	47 27 N	0
44 37 N	0.0	Sebastopol	33 32 E	44 25 N	+ 1
38 15 N	0.1	Sendai	140 52 E	38 04 N	4
47 07 N	0.2	Seven Falls	70 50 W	46 56 N	1
46 33 N	0.1	Shawinigan Falls	72 46 W	46 21 N	1
44 57 N	0.3	Simferopol	34 07 E	44 45 N	2
57 03 N	0.0	Sitka	135 20 W	56 52 N	— 3
42 42 N	0.6	Sofia	23 20 E	42 31 N	+ 3
47 44 N	0.7	Spokane	117 21 W	47 32 N	1
37 25 N	0.1	Stanford University	122 11 W	37 14 N	4
53 51 N	0.1	Stonyhurst	2 28 W	53 40 N	— 2
48 35 N	0.1*	Strasbourg	7 46 E	48 24 N	0
48 46 N	0.4	Stuttgart	9 12 E	48 35 N	0
19 03 S	2.9	Sucre*	65 16 W	18 56 S	13
34 21 N	0.1	Sumoto*	134 53 E	34 10 N	5
18 03 S	0.0	Suva	178 24 E	17 56 S	10
56 50 N	0.3	Sverdlovsk	60 38 E	56 39 N	— 3
33 52 S	0.0	Sydney*	151 12 E	33 41 S	+ 5
41 20 N	0.5*	Tachkent	69 18 E	41 08 N	3
19 24 N	2.3	Tacubaya	99 12 W	19 17 N	12
25 02 N	0.0	Taihoku	121 31 E	24 53 N	8
18 55 S	1.4	Tananarive	47 33 E	18 48 S	11
58 23 N	0.1*	Tartu	26 43 E	58 12 N	— 3
45 01 N	0.1	Théodosia	35 23 E	44 49 N	+ 1

Table 3 (Continuation).

Geographic Latitude β	Height above sea level h in km.	Station	Longitude (Greenwich) β	Geocentric Latitude α	Height above (+) or under (—) sphere with $r = 6366$ km. H in km.
° ′			° ′	° ′	
44 47 N	0.0	Technology (Machias) . .	67 21 W	44 35 N	1
41 43 N	0.4	Tiflis	44 48 E	41 32 N	3
37 06 N	1.2	Tinemaha	118 16 W	36 55 N	6
35 43 N	0.0	Tôkyô (Imp. Univ.) . . .	139 46 E	35 32 N	5
35 41 N	0.0	Tôkyô (Centr. Met. Obs.)	139 46 E	35 30 N	5
39 52 N	0.5	Toledo	4 02 W	39 40 N	4
43 40 N	0.1	Toronto	79 24 W	43 28 N	2
40 49 N	0.0	Tortosa*	0 30 E	40 38 N	3
36 04 N	0.1	Tsingtao	120 19 E	35 53 N	5
32 15 N	0.8	Tucson	110 50 W	32 04 N	7
35 44 N	0.0	Tyôsi	140 52 E	35 33 N	5
50 48 N	0.1	Uccle	4 22 E	50 36 N	— 1
39 08 N	0.2	Ukiah	123 13 W	38 57 N	+ 4
33 27 N	0.1	Usionomisaki	135 46 E	33 16 N	6
59 51 N	0.0	Upsala	17 38 E	59 41 N	— 4
45 26 N	0.0	Venezia	12 20 E	45 14 N	+ 1
48 25 N	0.1	Victoria B. C.*	123 19 W	48 13 N	0
43 07 N	0.0*?	Vladivostok	131 57 E	42 56 N	2
41 17 S	0.1	Wellington	174 46 E	41 06 S	3
48 15 N	0.2	Wien	16 22 E	48 03 N	0
44 30 N	0.1	Yalta	34 10 E	44 18 N	2
45 49 N	0.2	Zagreb	15 59 E	45 37 N	1
31 12 N	0.0	Zi-ka-wei	121 26 E	31 01 N	6
37 29 N	0.1	Zinsen	126 38 E	37 18 N	4
47 22 N	0.6*	Zürich	8 35 E	47 11 N	1

fully against all available sources. As we propose later to publish a list of corrections and additions, we shall much appreciate having our attention drawn to any errors.

In conclusion we wish to recommend that in future all seismological calculations, and all publications of travel times, be carried out in terms of the central angle Δ, computed with the use of geocentric latitudes. Precise work should also take into consideration the effect of the variation of radius, which corresponds to the varying values of H as given in table 3. Arc distances "over the surface" had best be given in terms of the sphere of 40000 km. circumference.